Measurements of Top Quark Pair Production @ CDF

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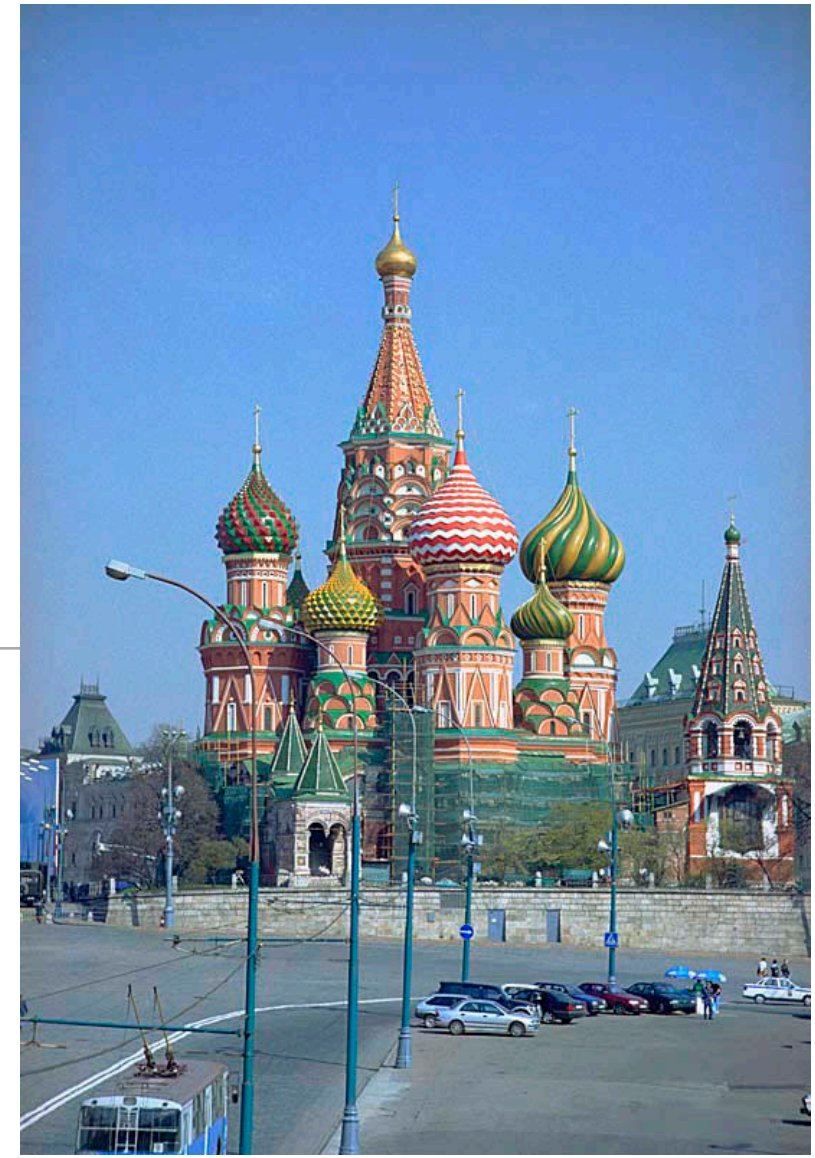

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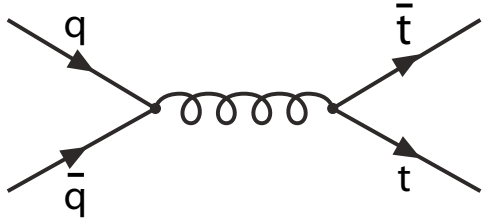
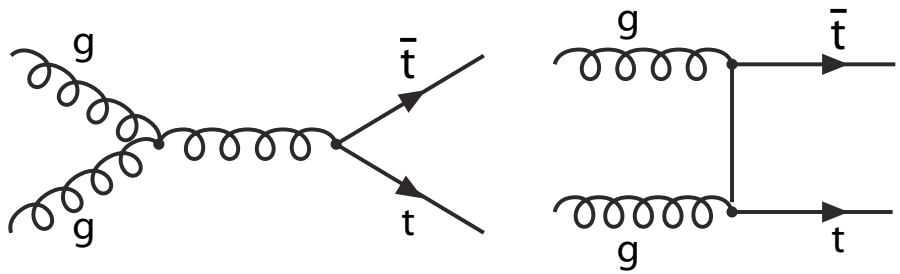
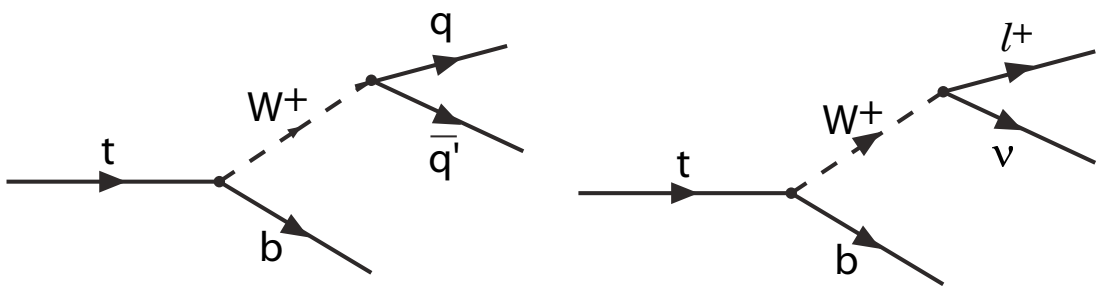
Basic Top Physics

- Top quarks at the Tevatron are dominantly pair-produced via the strong interaction
  - Quark/Anti-quark annihilation (~85%)
  - Gluon Fusion (~15%)
- Top quarks decay through the weak interaction into a b quark and a W boson
  - So much phase space, $\tau \sim 10^{-25}$ s
  - No time to hadronize
- We classify our analyses based on the subsequent decay of the two W's



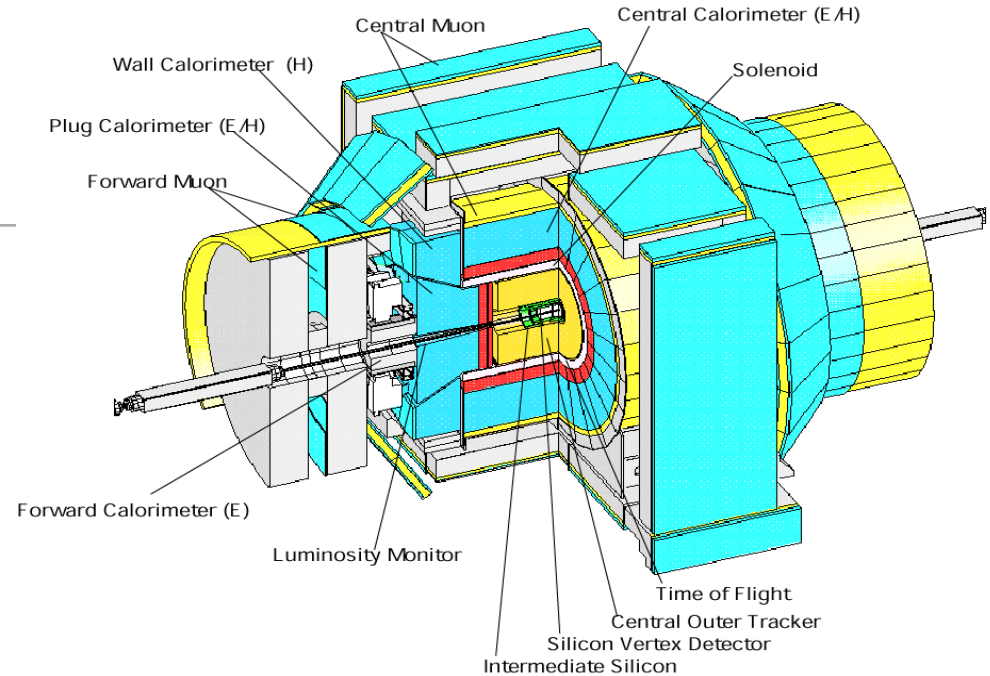


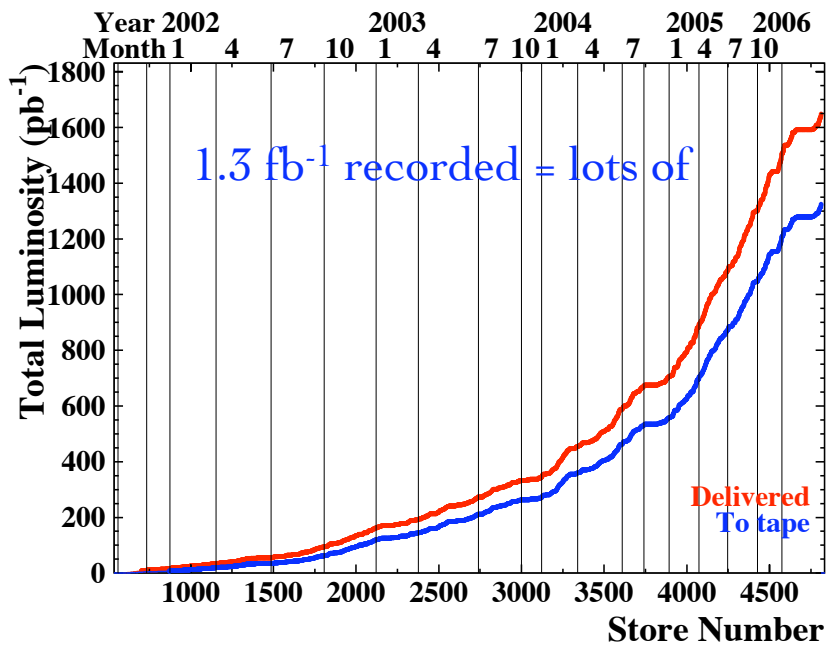


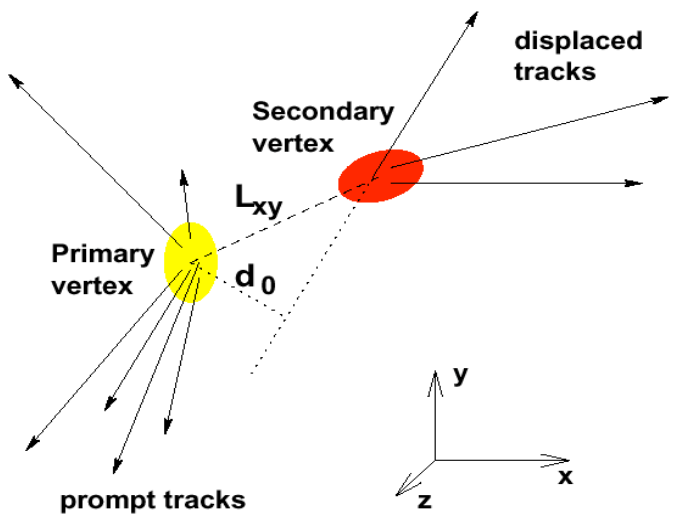
Experimental signatures will thus contain some combination of uds-jets, b-jets, leptons and missing energy depending on the decay mode being analyzed

CDFII Detector and the Tevatron

- CDFII is well suited to finding and measuring top quarks
  - Drift chamber in a 1.4 T solenoidal field
  - Calorimetry to $|\eta| < 2.5$
  - 722,000 channel Si vertex detector to tag b-quark jets



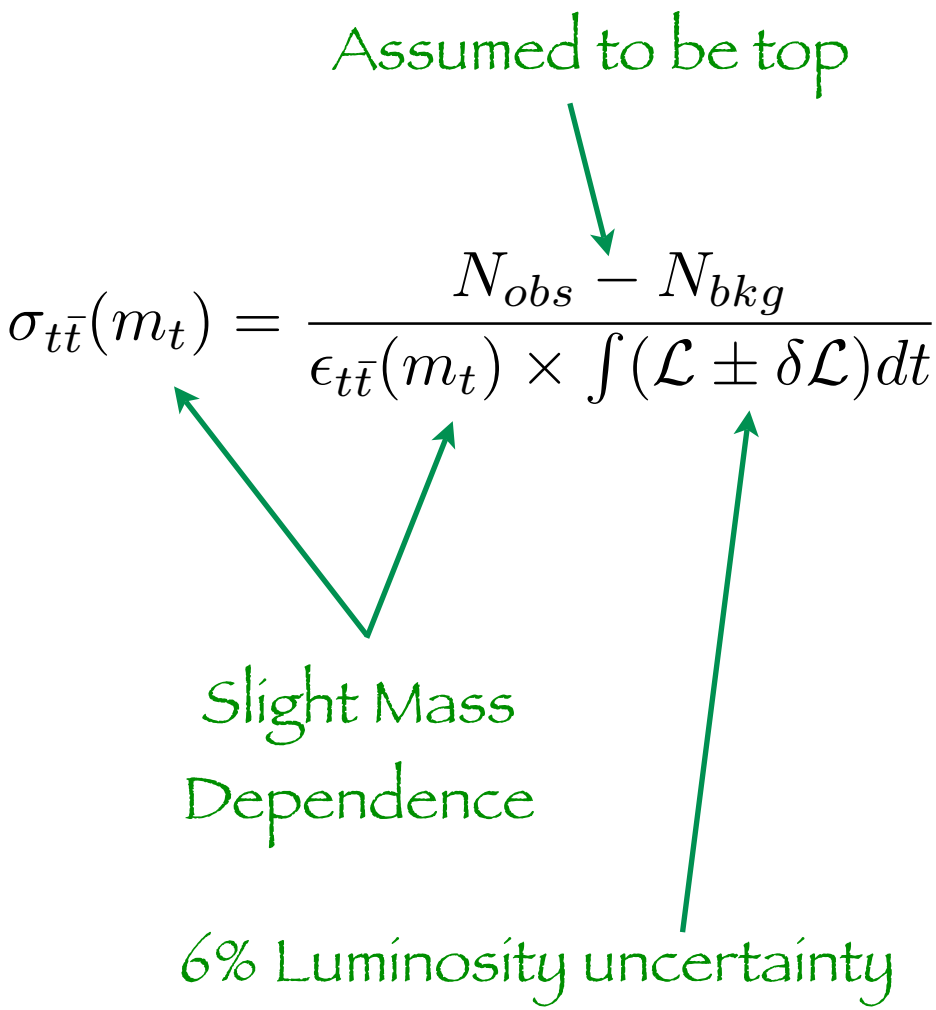




It also helps that, at this point in Run 2, we have lots of data!

How we measure top cross-sections

- Most (but not all) top cross-section measurements at CDF are simply counting experiments
- Several important things to note:
  - Excess above background is attributed to top
  - Signal efficiency and resultant cross-section depends on an assumed mass for the top quark
  - All measurements have the same 6% uncertainty on their central values due to the precision with which we can luminosity at CDF



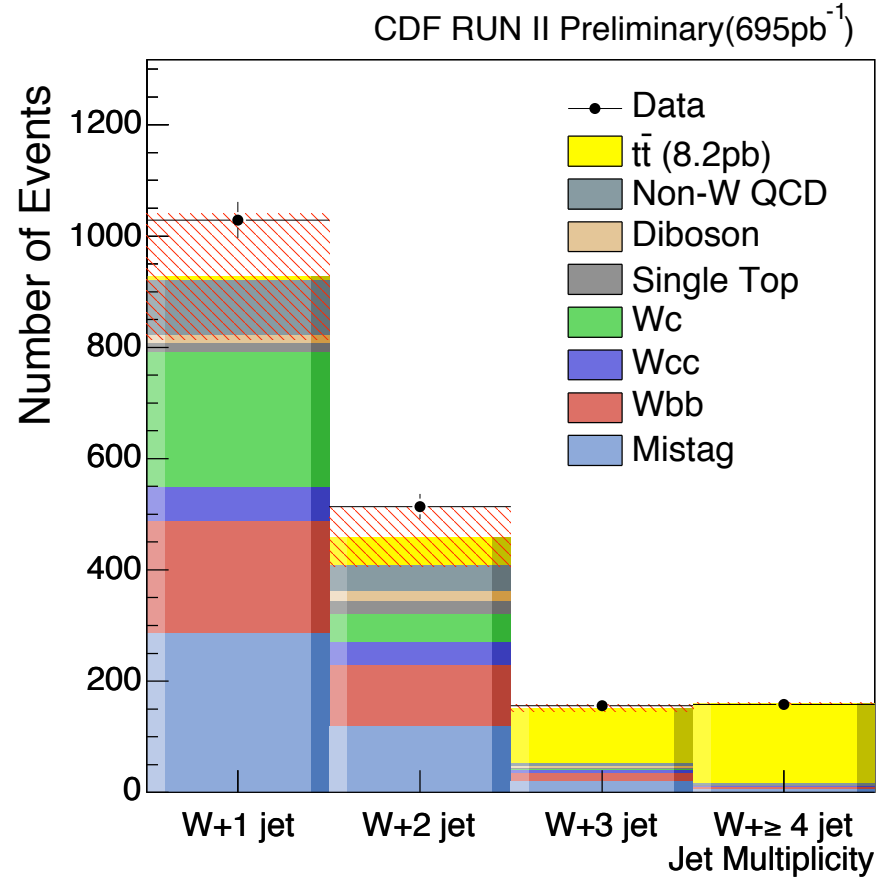
Top Pair Production is simply QCD, right?

- The Nobel for QCD has already been given out, so what are we testing with Tevatron data?
- Since we measure "top" as excess over background, a significantly high cross-section relative to the SM expectation would indicate new physics in our "top" sample such as
  - A resonance decaying to ttbar
  - Supersymmetry (e.g. stop)
  - A new heavy quark, T'
- We also test the SM by checking for consistency in our measurements across all possible decay modes

Fellow Santa Barbarian, David Gross receiving his 2004 prize

Lepton + Jets Measurements: $t\bar{t} \longrightarrow b\bar{b}'\ell\bar{\nu}q\bar{q}'$

- This is the "golden mode" for top physics
  - Large branching fraction (~30%)
  - High S/B
- Events are selected by requiring:
  - 1 (and only one) isolated lepton (e,μ) with $p_T > 20$ GeV
  - Missing $E_T > 20$ GeV
  - 3 or more jets with $E_T > 15$ GeV , 1 of which has been b-tagged (secondary-vertex)

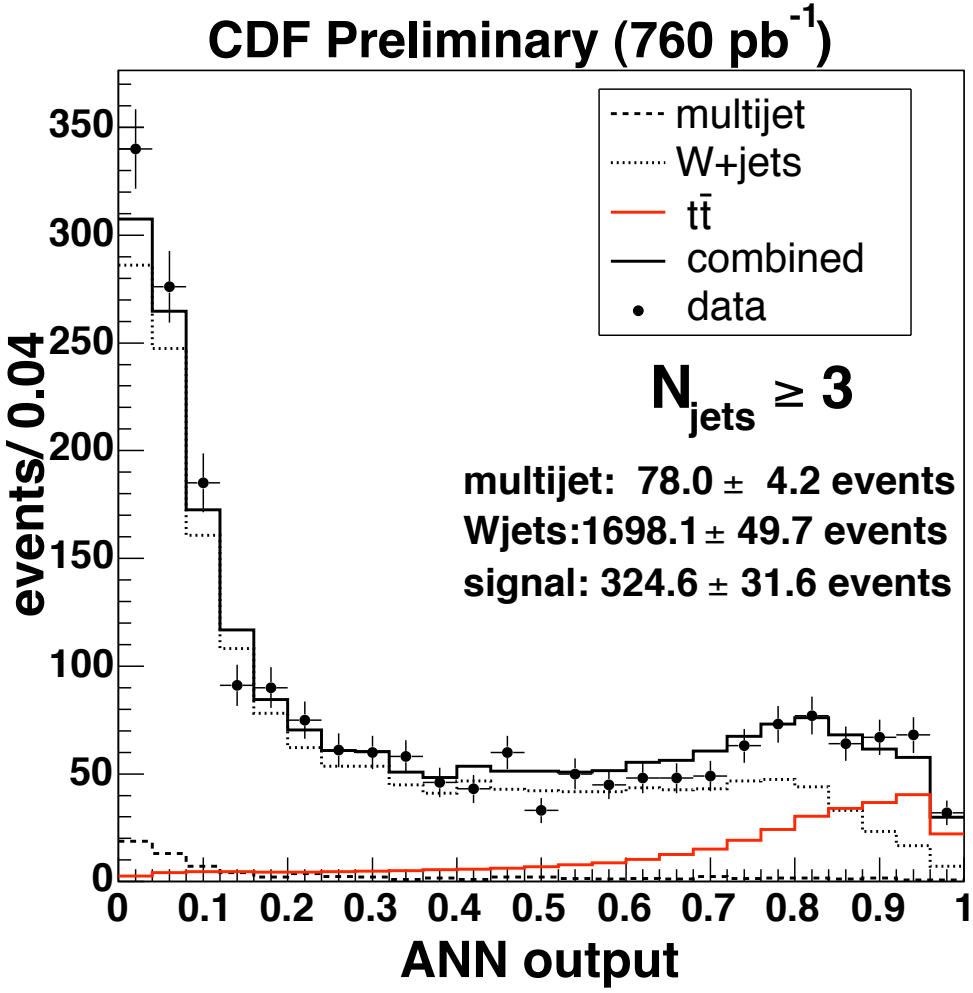


$$\sigma_{t\bar{t}} = 8.2 \pm 0.6\ (stat.) \pm 1.0\ (syst.)\ pb$$

(Note: Here the b-tag is really what distinguishes top from W+jets backgrounds)

More Lepton + Jets Measurements: $t\bar{t} \rightarrow b\bar{b}'\ell\bar{\nu}q\bar{q}'$

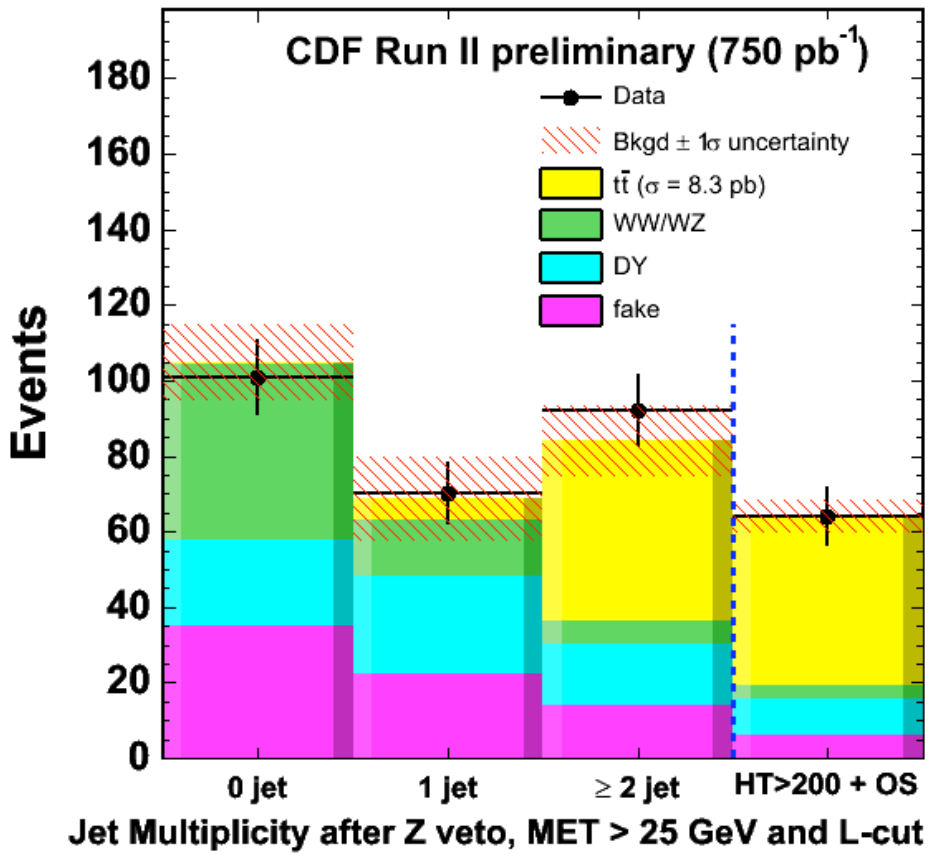
- A Complementary Analysis:
  - Similar event selection, but
  - Instead of a b-tag, exploit kinematic differences between top and W+jets
  - Use a Neural Network trained on 7 distinguishing variables
    - e.g. H_T (scalar sum of jet, lepton & missing energies)
  - Different systematics, useful in combined results



$$\sigma_{t\bar{t}} = 6.0 \pm 0.6\ (stat.) \pm 0.9\ (syst.)\ pb$$

Dilepton Measurements: $t\bar{t} \rightarrow b\bar{b}'\ell\bar{\nu}\ell\bar{\nu}$

- Small Branching Fraction (~5%), but
- CDF has very good lepton ID
  - Doubly leptonic modes are therefore very "clean"
  - No b-tag needed to attain reasonable S/B
- Events are selected by requiring:
  - 2 isolated leptons (e,μ) with p_T > 20 GeV
  - 2 or more jets with E_T > 15 GeV
  - Missing E_T > 25 GeV
  - Two leptons must be oppositely charged and not form a Z boson
  - H_T > 200 GeV

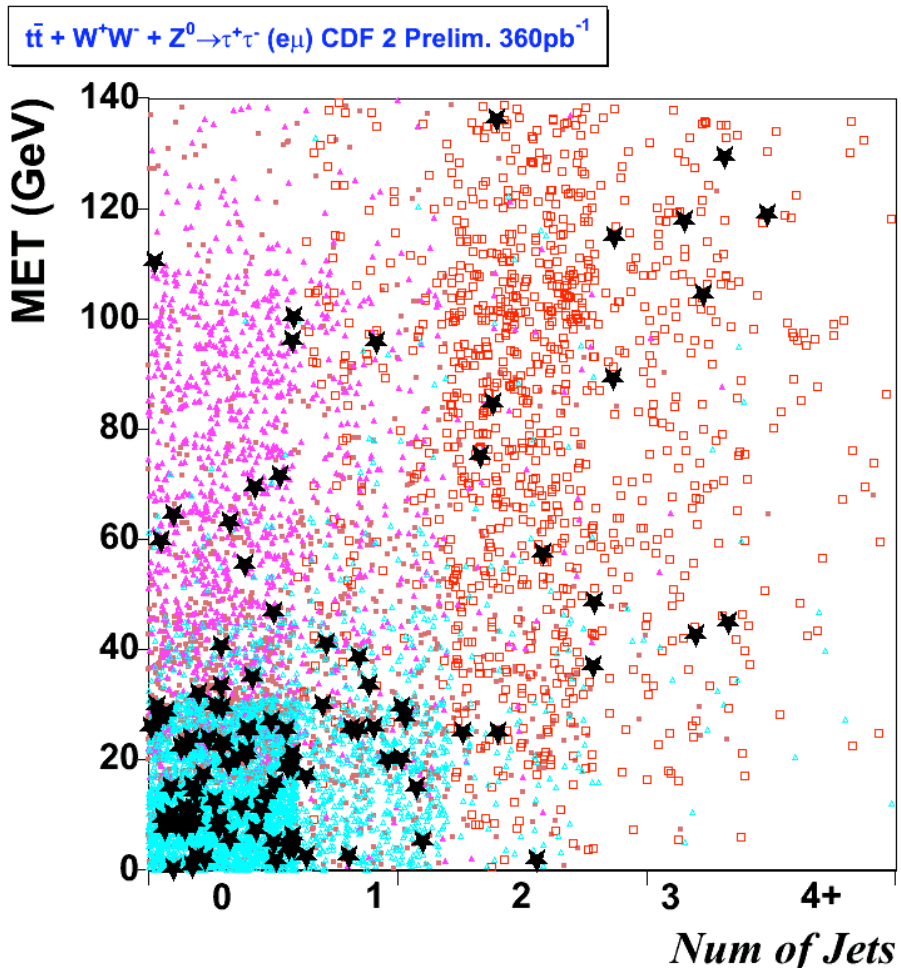


$$\sigma_{t\bar{t}} = 8.3 \pm 1.5\ (stat.) \pm 1.1\ (syst.)\ pb$$

An Inclusive Dilepton Analysis:

$$WW \to \ell\bar{\nu}\ell\bar{\nu}$$
$$t\bar{t} \to b\bar{b}'\ell\bar{\nu}\ell\bar{\nu}$$
$$Z \to \tau^+\tau^-$$

- Dileptonic decays of top pairs are not the only source of two lepton events at CDF
  - Drell-Yan decaying to taus
  - WW decaying to leptons
- Similar event selection, but
  - No cut on N_{jet}
  - Fit data for top, WW, Z components using the distinct event topologies
  - Simultaneously measure cross-sections for the three processes

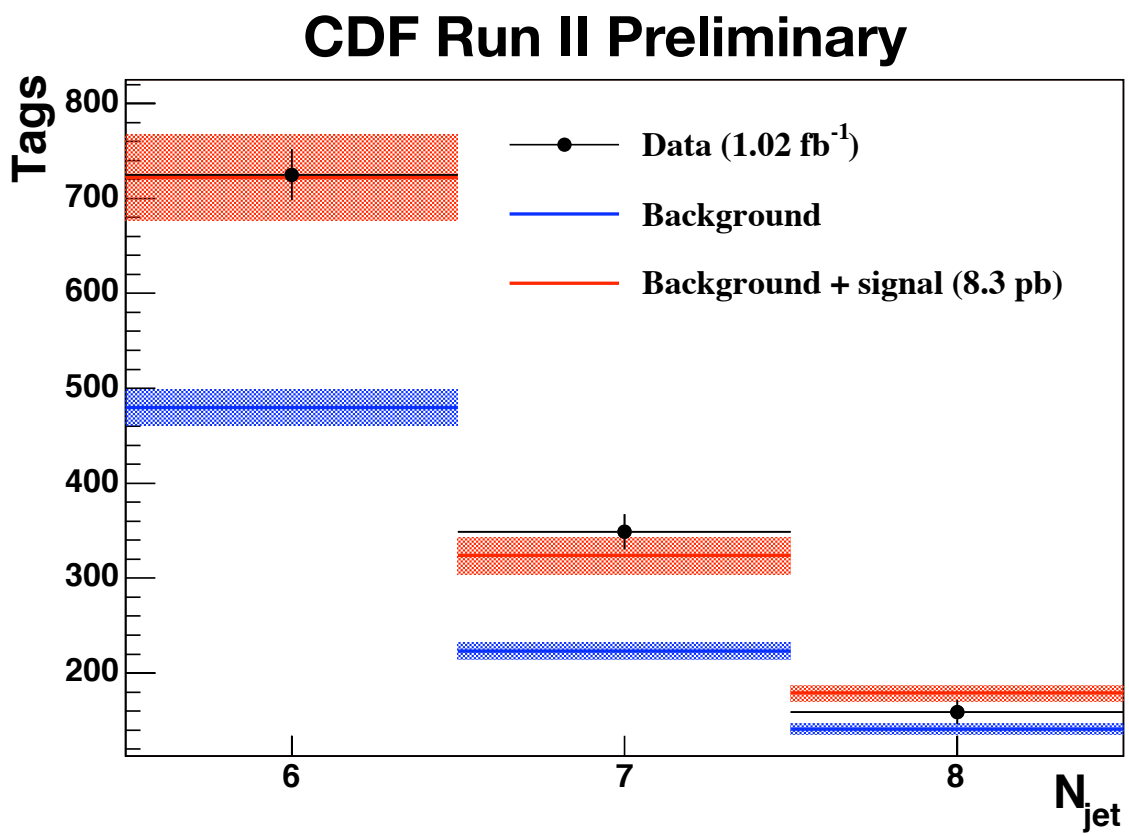


$$\sigma_{t\bar{t}} = 8.5\ ^{+2.6}_{-2.2}\ (stat.)\ ^{+0.7}_{-0.3}\ (syst.)\ pb$$

All-Hadronic Measurement: $t\bar{t} \longrightarrow b\bar{b}'q\bar{q}'q\bar{q}'$

- Large branching fraction (~40%)
- Low S/B
  - Large QCD backgrounds
- Events are selected by requiring:
  - No isolated leptons (e,μ) and No significant Missing E_T
  - 6-8 jets well separated ($\Delta R > 0.5$) jets with $E_T > 15$ GeV of which 1 has been b-tagged (secondary-vertex)
  - Signal like topology using NN trained on 11 kinematic variables
    - E.g. ΣE_T, centrality, aplanarity, dijet & trijet masses

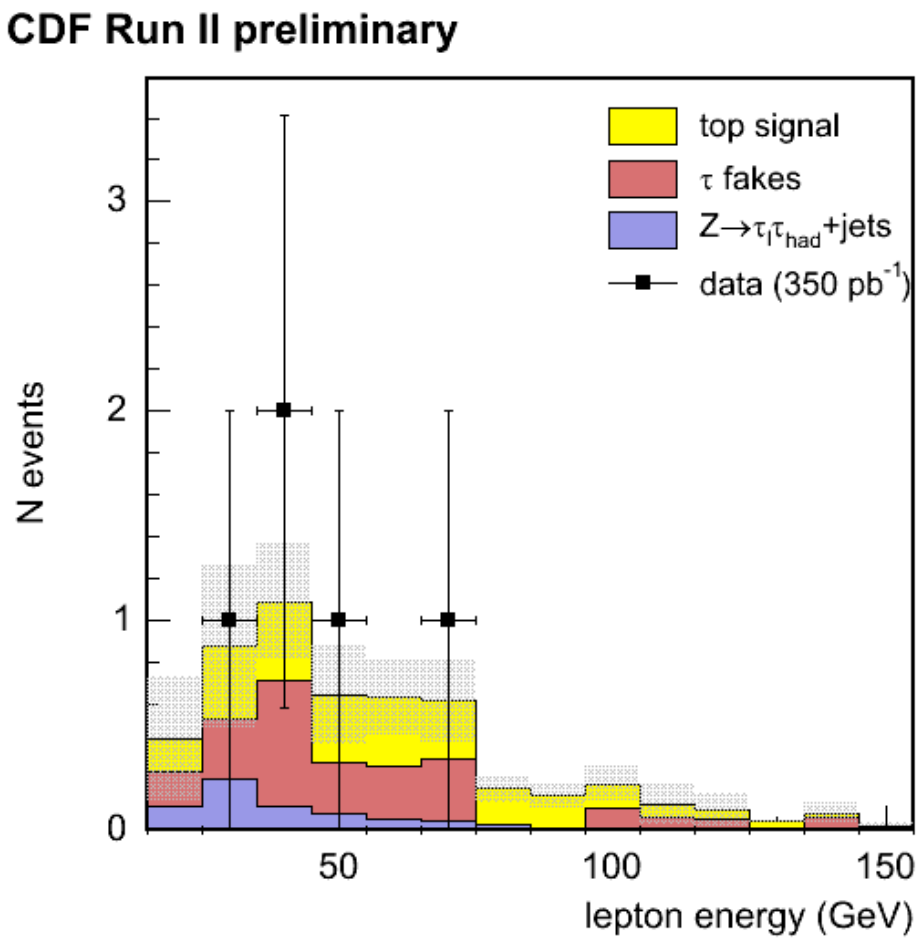
$$\int \mathcal{L}dt = 1.02\ fb^{-1}$$



$$\sigma_{t\bar{t}} = 8.3 \pm 1.0\ (stat.)\ ^{+2.0}_{-1.5}\ (syst.)\ pb$$

Search for Tau+Lepton Mode: $t\bar{t} \rightarrow b\bar{b}'\tau_h\bar{\nu}\ell\bar{\nu}$

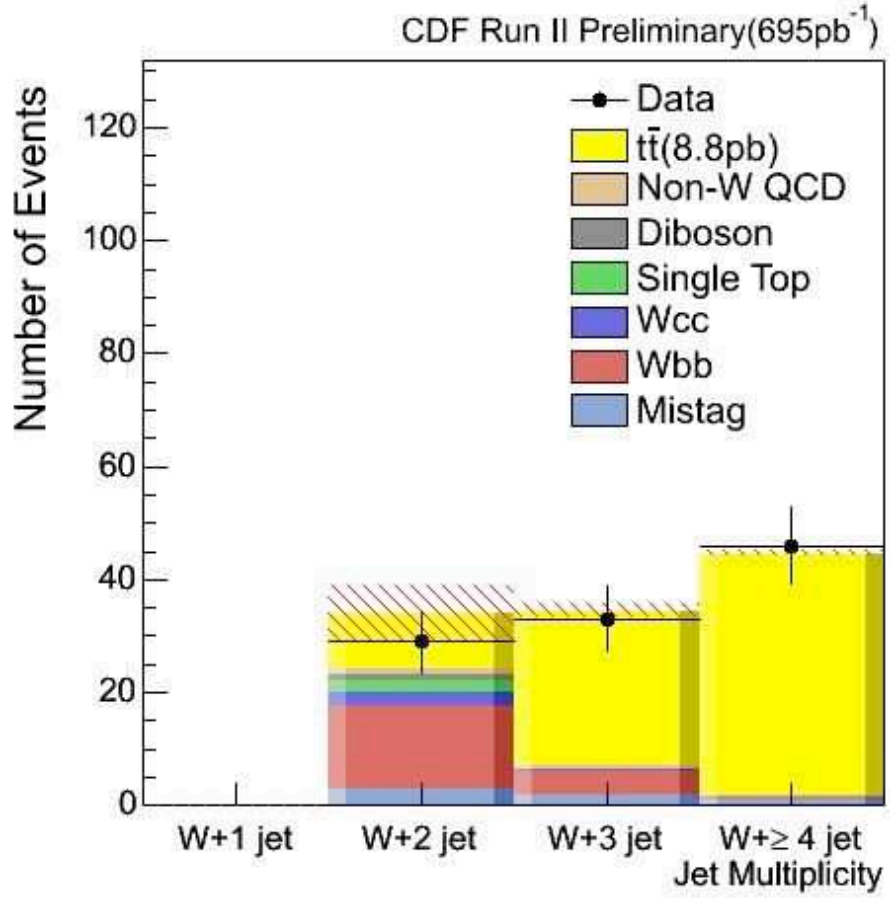
- Very small branching fraction (few %)
  - Has not yet been observed
- Events are selected by requiring:
  - 1 isolated lepton (e,μ) with $p_T > 20$ GeV
  - 1 isolated hadronic tau (1 or 3 pronged) with $E_T > 15$ GeV
  - Missing $E_T > 20$ GeV
  - 2 jets with $E_T > 25$ and 15 GeV
  - $H_T > 205$ GeV
  - Passes $Z \rightarrow \tau\tau$ veto



5 candidate events observed on a background of 2.7 ± 0.4 events
(p-value of 15%, or 1 sigma excess consistent with the SM expectation)

Other CDF Measurements & Cross-checks:

- Additional measurements (which I don't have time to cover) are performed which serve as useful cross-checks
  - Lepton+Jets with Double tags
    - Extremely high purity
  - Lepton+Jets with alternative b-tagging algorithms
    - NN, Loose, Ultra-Tight, Jet-Probability & Soft Lepton Taggers
  - Dilepton with Lepton+Track
    - Adds acceptance for taus
  - E_T^{miss} + Jets
    - Lepton ID not required

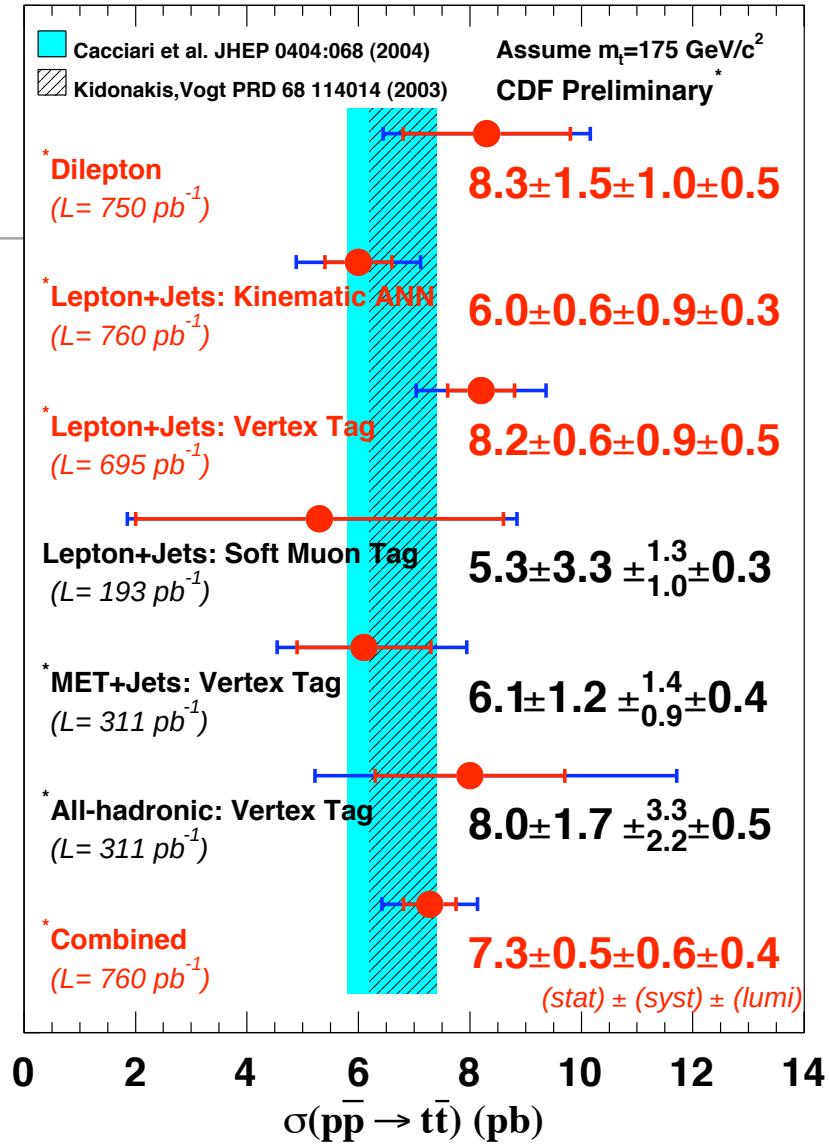


Double-Tagged Results

$$\sigma_{t\bar{t}} = 8.8\ ^{+1.2}_{-1.1}\ (stat.)\ ^{+2.0}_{-1.3}\ (syst.)\ pb$$

Combined Measurement:

- CDF has combined 6 of their measurements in the dilepton, lepton+jets and all hadronic channels
  - Integrated luminosities of up to 760 pb^{-1} used
  - m_t = 175 GeV assumed
  - Best Linear Unbiased Estimator method used to combine results
  - Correlations of statistical and systematic errors taken into account



$$\sigma_{t\bar{t}} = 7.3 \pm 0.5\ (stat.) \pm 0.6\ (syst.) \pm 0.4\ (lumi.)\ pb$$

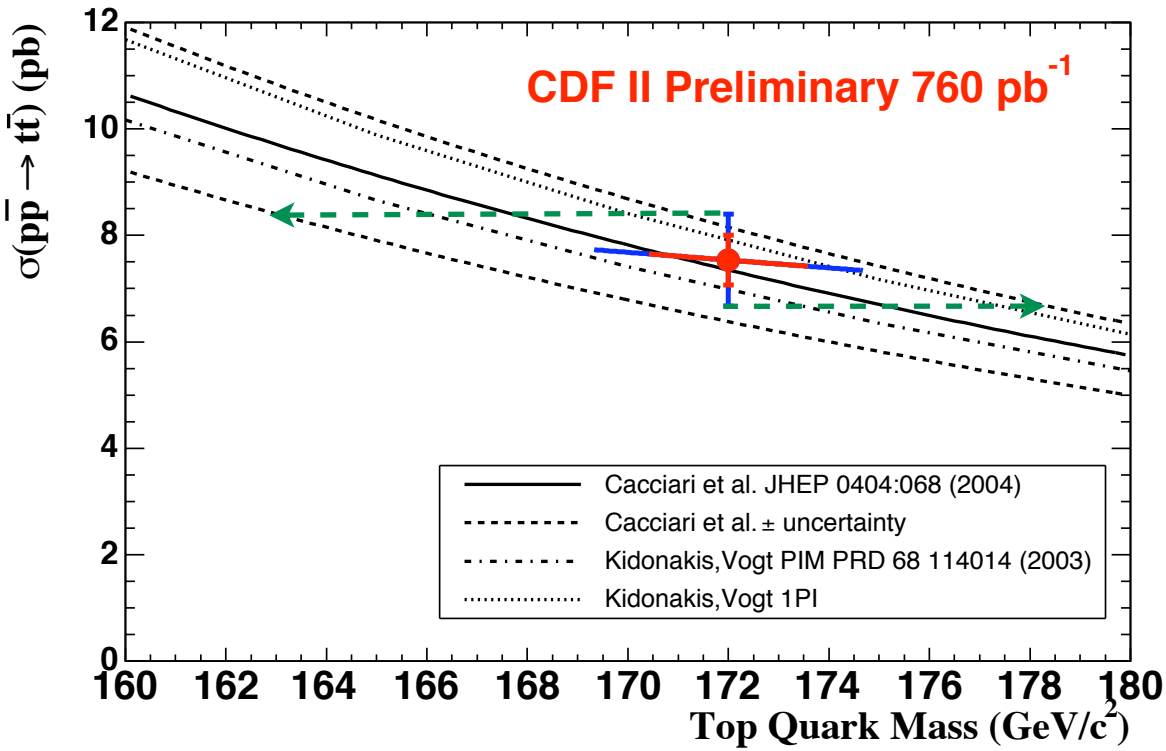
(The precision of this measurement is comparable to the theoretical uncertainty in calculations of σ_{tt})

On the mass Dependence of the Result

- To first order the mass dependence of the result due to $\epsilon(m_t)$ is negligible, shown as the nearly horizontal red-blue line in the graph at right.
- If we make this assumption, and take the central value and vertical error bars on the CDF combined result as input to an inverted SM calculation for $\sigma(m_t)$ we can bound the top quark's mass from our cross-section measurements
- I have done this with Cacciari et al, taking into account the theoretical uncertainty, (show in green dashed arrows at right) and find:

$$m_t = 171.2^{+7.2}_{-8.2}\ GeV/c^2$$

N.B. Not an "official" CDF result



A precision of 4.5% on m_t simply by performing counting experiments alone!

Summary & Conclusions

- CDF has now has now collected a sample of data with over 10x that used to discover the top quark

- The most recent analyses of this data are consistent with the hypothesis that the ttbar is being produced in accordance with expectations from QCD

- The latest combined CDF result for the top pair-production cross-section is:

$$\sigma_{t\bar{t}} = 7.3 \pm 0.5\ (stat.) \pm 0.6\ (syst.) \pm 0.4\ (lumi.)\ pb$$

- The precision of this measurement is comparable to the theoretical uncertainty in calculations of σ_{tt}